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MOTION SICKNESS AND SPATIAL PERCEPTION

A THEORETICAL STUDY

JACK E. STEELE, MAJOR, USAF (MC)

BIOMEDICAL LABORATORY
AEROSPACE MEDICAL LABORATORY

NOVEMBER 1961

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This study was conducted in the Bioacoustics Branch of the Aerospace Medical Laboratory, Aeronautical System Division, under Project 7210, Task 71201, "Complex Response of the Individual to Acoustic Energy" and under Project 7232, Task 71789, "Physical and Physiological Response to Acoustic and Vibratory Energy."

ABSTRACT

Theories of motion sickness are reviewed and compared with a new theory in which the activity of the central nervous system is more important than the intensity or modality of sensory stimulation. Concepts treated are the development and validation of an inertial reference frame; the perceptual transformation of sensory data, which reduces its content, increases its reliability and can incorporate compensations for environmental variables; and the consequences of perceptual inadequacy.

PUBLICATION REVIEW

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INTRODUCTION

A comparison and discussion of existing theories of motion sickness is reviewed with a new theory in which the activity of the central nervous system is more important than the intensity or modality of sensory stimulation. This theoretical study of motion sickness was motivated partly by the superficial similarity existing between its symptoms and those developing in some men when exposed to a loud noise field (jet engines) (ref. 16). There was further similarity in the possibility that these conditions were both produced by excessive sensory stimulation.

Motion sickness is of theoretical interest as one of the simplest functional diseases of the nervous system. Its minimal emotional aura and social stigma facilitate objectivity. It is truly functional. Its production requires no pathogenic substance or organism; no excess or deficiency of any physical substance and no destructive physical forces. Nearly everyone is susceptible. Whether or not motion sickness develops in a given subject in a particular situation depends mainly on that subject's previous sensory experience.

SYMPTOMS AND DESCRIPTION

Motion sickness is a convenient generalization referring to a syndrome that may be produced in a variety of ways. The symptoms vary with the individual differences of the subject and possibly with the exact nature of the stimulus situation. One might defend such subcategories as car sickness, train sickness, boat sickness, air sickness, elevator sickness, motion picture sickness, etc. There may be some slight differences in symptoms as they are elicited by these different stimulus patterns. Of even greater interest is a possible enlargement of the concept, or at least consideration, of the common features it shares with other conditions in which the information content of relatively mild stimuli is adequate to elicit nausea, vomiting, changes in blood pressure, and other significant physiological changes. Such stimuli and the responses they arouse are variously tinged with emotion depending on the degree to which conscious intervention by the subject is normally required in dealing with the situation.

The study of motion sickness is very old beginning many centuries ago with the study of sea sickness. It was recognized in the last century (ref. 40) that the sea was not essential to this syndrome and a similar sickness could be produced by various other motions than travel by water. The necessity for large scale troop movements in World War II stimulated a large amount of research on the cause and possible prevention of motion sickness. This work is reviewed by Taylor and Bard (ref. 57).

Most authors agree that the essential part that motion plays in the production of motion sickness is the stimulation of the subjects nervous system. It makes little difference then whether the subject moves, or his environment, or both. The subject is usually not certain just what is moving or in what manner. Some authors would differentiate between the condition produced by movement of the subject and that produced by movement of his visual environment (ref. 36). However, subjectively and symptomatically there is little difference between the two situations.

Nausea and vomiting are the cardinal symptoms of motion sickness. However, the syndrome is much larger than this and the symptoms usually develop in fairly orderly sequence. The earliest to develop are psychological; first to appear are a decreased spontaneity and increased carelessness in the performance of routine duty. This may progress to the point of drowsiness, and yawning is the first obvious sign. Cold sweat and facial pallor appear. Subjectively, the experience may be reminiscent of fear, though introspectively no fear is present. The full syndrome may certainly develop in the absence of any conscious fear. As symptoms progress salivation and swallowing occur, then nausea and vomiting. There is malaise or a general feeling of sickness which may be differentiated from the accompanying vomiting due to other causes. Early there is muscle tenseness that later gives way to weakness and trembling, with an unsteady gait. Some spatial disorientation is usually present, manifested by such subjective observations as a tilting horizon. This symptom disappears promptly when spontaneous remission occurs.

The symptoms appear to be due to activity of the autonomic nervous system, in general an excessive parasympathetic discharge; thus the efficacy of atropine, scopolamine, etc. However, a small percent (5 percent in one study) (ref. 54) seem to show excessive sympathetic activity. Goehring and Schwab report that 1 mgm of prostigmine intramuscularly (I. M.) (ref. 26) caused nausea and vomiting in 80 percent of seasick susceptible subjects, but in only 14 percent of resistant subjects. Because of the complexity of the autonomic nervous system and its pharmacoogy and well known individual differences, it is not to be expected that pathological response in all subjects, even when elicited by identical stimuli, will be identical. The same experience may produce apoplexy in one individual and fainting in another.

Numerous physiological changes have been recorded, but they are relatively inconsistent and do not correlate well with either the presence of symptoms or the degree of susceptibility. Blood sugar rises with exposure to motion but does not correlate with the presence or absence of symptoms. Blood phosphorous decreases but shows the same lack of correlation with symptoms (ref. 38). Pulse (refs. 13, 38), respiration and blood pressure may shift in either direction. Central retinal (refs. 21, 14, 15) artery pressure, and presumably intracranial blood pressure, may rise more in susceptible than in nonsusceptible subjects when they are exposed to motion in a horizontal plane, that is, periodic acceleration parallel to the long axis of the body while in a supine position. Palmer skin resistance decreases but it cannot be correlated with symptoms (ref. 44). Stomach atony and hypomotility usually accompany the nausea (ref. 26). No regular electroencephalographic changes have been found in motion sickness, though some abnormalities may develop in severe cases. The duration of after sensation following angular acceleration is correlated positively with susceptibility to motion sickness (ref. 21). Antidiuresis correlates highly with the occurrence of nausea in experimental (ref. 56) motion sickness.

ETIOLOGICAL THEORIES

Theories of the cause of motion sickness fall readily into two main classes. The older theories include travel at sea, movement of masses in the body, such as viscera or blood and psychogenic origins. All modern theories have in common reference to stimulation of the nervous system. They differ in what constitutes the essential features of such stimulation.

Overstimulation is widely held to be the main factor. Experimental studies inspired by this view usually take one of two approaches: the identification of a specific sensory end-organ, the excessive stimulation of which uniquely produces motion sickness, or the analysis of the stimulus to discover how much energy or what pattern of stimulus is effective in producing symptoms.

There is another view, that no single end-organ is uniquely responsible. It may go further to hold that the interaction of stimulation of different end-organs is essential. The modality conflict theory is the best example of this group.

Psychobiological disorientation has been suggested as the essential feature causing motion sickness (ref. 44). The concept is somewhat vague, but an important feature is that it goes a step further in discounting the importance of strength or severity of the stimulus. It emphasizes the information content of the stimulus and even more important the significance of what the subject does with that information.

Finally, the theory offered by the present writer emphasizes the importance of the type and quantity of perceptual activity aroused in the subject; activity akin to heightened vigilance. The use of the term "perceptual" is not to imply that the activity is conscious, but that it is a representation of reality achieved by analysis and integration of data from various sensory modalities.

DISCUSSION OF THEORIES

Ocean travel long ago lost its position as the sole cause of motion sickness. Fear and other psychological factors may contribute to the development of symptoms in some cases but certainly the majority of those who become sick in experimental situations are not frightened and some are amused. Hemingway (ref. 38) reported that of 344 subjects who had flown more than 30 hours without air sickness, over 10 percent vomited within 20 minutes while serving as subjects on a swing. Psychogenic factors can contribute to the nausea of motion sickness just as they can contribute to nausea occurring in other circumstances, but certainly they are not essential to the production of motion sickness.

The shifting of body masses is one of the older explanations offered as the cause of motion sickness. This is undoubtedly due to the obvious abdominal symptoms. Experimental data relating hydrostatic pressure shifts in the cardiovascular system to motion sickness are the observations of G. DeWitt (refs. 14, 15) and of Van Egmond (ref. 21) who swung supine subjects in a parallel swing and measured the lability of their retinal blood pressure. DeWitt concluded, "The specific seasick therefore show, on stimulation of the otoliths, a certain degree of vaso-lability which is absent in normal persons." The attempt to prevent motion sickness by a rigid restraint on the body designed to decrease movement of the abdominal organs or shift of blood in the body has been notably unsuccessful. Further, in vibration experiments maximum shifting of abdominal organs occurs at three to five cycles per second. It causes pain but no motion sickness. Manning and Stewart (ref. 47) using swings and different body and head positions have investigated the effect of the direction of the acceleration through the body and through the head. The results of these experiments show that acceleration of the body is relatively unimportant in the production of motion sickness. The direction of the acceleration of the head is significant. Accelerations in the vertical direction are quite effective, while those from front to back of the head are relatively ineffective in producing symptoms. This may be related to the importance of compensating for the effects of varying g on both motor behavior and on the circulatory system.

IMPORTANCE OF SENSORY MODALITY

In the inner ear are sense organs sensitive to both linear and angular acceleration. The most widely held current belief concerning motion sickness is that it is caused by overstimulation of these sense organs. The strongest support for this belief is the observation that in experimental animals, their destruction abolishes motion sickness produced by swings. Human subjects lacking functional inner ears are not sickened. Semicircular canals, because of their obvious association with dizziness, have received undue attention. The ease with which they may be stimulated in the laboratory and the effectiveness of such stimulation in provoking motion sickness symptoms undoubtedly have contributed to this overemphasis. The identification of the symptoms produced by angular accelerations with general motion sickness led to several misunderstandings. For example, the angular velocities reached in such experiments are so great that nystagmus is inevitably present. This presence of nystagmus in motion sickness produced by angular acceleration in the laboratory led many people to seek nystagmus under other conditions of motion sickness and to offer various explanations for its absence. Nystagmus is absent from most normally occurring motion sickness because the angular motions involved are so small, being often at or below threshold (ref. 15). Parallel swings and elevators are quite adequate for the production of motion sickness. They submit the subjects to no angular accelerations, thus proving conclusively the nonessential nature of stimulation of semicircular canals for the production of motion sickness.

The importance of linear acceleration in the most common forms of motion sickness led to the recognition of the importance of the otolith organs. These organs have not received the overemphasis accorded the semicircular canals. They are the sense organs of greatest importance in linear accelerators such as elevators and parallel swings. One of the simpler and more effective methods of reducing motion sickness is the assumption of the supine position. The effectiveness of this position has been demonstrated experimentally to be due to head rather than body position. The otolith organs are sensitive to both quantity and direction of linear acceleration. The role played by the latter in the production of motion sickness has been considered in the analysis of some of the swing experiments (ref. 47).

The role of vision in the production of motion sickness has been rather controversial. It has been said that seasickness occurs only in people showing ocular muscle imbalance. Actually, symptoms such as cold sweat, nausea, and even vomiting may be produced by visual stimulation alone, that is, when the subject is not moving (refs. 12, 49, 63). The production of motion sickness by visual stimuli alone is not usually possible by the mere movement of something in the visual field. It must involve movement of the visual reference frame. For example, symptoms have been produced by rotating a cylinder which completely enclosed the subject (refs. 12, 58).

Vision is one of our most important senses and it contributes most of our information about the motion of ourselves and parts of our environment. Motion sensed only visually is quite adequate to produce motion sickness. Simple rotation of the visual environment at 12 revolutions per minute is most effective in producing automatic scanning of the eyes and producing symptoms of motion sickness (ref. 58). Crampton and Young (ref. 12) demonstrated a significant correlation between the susceptibility of a subject to sickness produced this way and their susceptibility to sickness produced by accelerations. In a significant group of experiments in which both the subject and his visual environment could be tipped independently about an anterior and posterior axis, Witkin (ref. 62) demonstrated the superiority of movement of visual field over actual movement of the subject for the production of motion sickness symptoms. He observed no illness with body movement alone, with or without vision. Body movement with room movement caused occasional mild discomfort; and several of his subjects requested that it be stopped after a few seconds. The greatest discomfort occurred at the points of reversal of direction of movement, that is, at the position of greatest angular acceleration. One unusually susceptible subject developed symptoms in a completely static situation. The highly structured visual field, the room, was merely tipped from the acceleration vertical. In these cases of visually induced symptoms, there can be no question of overstimulation of the inner ear.

Many viewers of Cinerama (ref. 63), in which the projected picture occupies a large part of the visual field, have experienced some motion sickness symptoms during scenes in which this rather large visual reference frame undergoes acceleration. Kohler (ref. 45), in some experiments in visual perception in which the visual field was reversed optically, found motion sickness symptoms as an incidental observation. These symptoms occurred when the subject first wore the reversing spectables and recurred when he first removed them. The occurrence of symptoms was reduced by the use of antimotion sickness drugs. Another example of visually induced motion sickness is that produced in a helicopter flight simulator, 2-FH-2. More than two-thirds of the subjects experienced some degree of sickness (ref. 51). The more experienced instructors seemed to be the most susceptible. Though there was conflict between visual and proprioceptive stimuli (the subjects did not actually move), Miller and Goodson concluded, "The problem seems to lie in one or a combination of several modes of distortion: There exist both static and dynamic distortions in the projected scenery; there are errors in the perceived directional changes of motion; and there are dynamic errors in the perceived angular rate of motion." These observers thought that presentation of a visual environment which was a distorted representation of a real environment was the main factor contributing to the sickness.

In summary, there is ample experimental evidence that relatively independent stimulation of any one of three separate sense organs can produce motion sickness. These organs are the semicircular canals, the otolith organs, and the eyes. The effect of the combined stimulation and interaction will be discussed later. Stimulation of the tactile proprioceptive kinesthetic sensory system, though rarely if ever proposed as a cause of motion sickness, should not be completely forgotten, because it does contribute to the total perception of motion and acceleration.

IMPORTANCE OF INTENSITY OF STIMULATION

Investigators seeking a single sense organ as cause of motion sickness are usually also concerned with the quantity of stimulation and sometimes with the quality of stimulation to that sense organ. The effect of quantity of stimulation has probably been best studied on the otolith organ. Wendt (refs. 1, 2) using a vertical acceleration pattern of alternating periods of decreased and increased acceleration each 3/5th of a second in duration and separated by periods of 1-g acceleration found that the most effective repetition rate for the complete cycle was about 16 per minute. Shortening the duration of the 1-g period, even though it yielded an acceleration pattern representing increased energy, produced less sickness. Fraser and Manning (refs. 23, 24) swinging men at

17 cycles per minute obtained maximum sickness at a g change of 0.9. Increasing the g change to 1.7 caused some reduction in sickness. The vertical acceleration producing maximum motion sickness is actually less than that experienced by a man running. Alexander, Cotzin, Hill, Ricciuti, and Wendt performed the most thorough study of the features of vertical acceleration that make it effective in the production of motion sickness. They varied the time interval between accelerations, the duration of accelerations, and the intensity and frequency of the accelerations. Their conclusions were that nausea and vomiting are produced most effectively by way of moderate frequency and acceleration and that "our hypothesis that the time characteristic of a motion rather than its violence is the feature relevant to motion sickness" has been confirmed.

Most people after becoming accustomed to a particular motion, ship, automobile, etc., are no longer made sick by that motion. However, they are still subjected to the same stimulation as before. The identical stimulus to which they are now immune can make others sick. Acquired immunity does not consist of raised thresholds of end-organs. The experienced aviator, far from losing sensitivity, is much more aware of small accelerations of his craft than is the novice.

In a very practical situation in a destroyer escort squadron, Bruner (ref. 9) has reported that a number of subjects "react paradoxically." Although these men are frequently ill during heavy swells and moderate seas, they report an actual decrease in their propensity to seasickness, amounting to complete immunity, in extremely rough weather when green water is taken over the bridge and rolls are frequently 30 degrees or more. "The moderately heavy, slow sinusoidal ground swell may be more likely to incapacitate the susceptibles than will a much stronger wave form that is broken up by high-frequency components."

That some portion of the nervous system is being overloaded or being called upon to function beyond its normal capacity is quite possible; that it is any sense organ is very unlikely. The level of angular accelerations encountered aboard ship is barely at the threshold of perceptibility (ref. 14); that encountered on swings is higher but still well within normal range of stimuli to the inner ear. The linear accelerations that may produce motion sickness are well within the normal limits of the sense organs involved and, further, the energy or violence of such linear stimulations is a relatively insignificant measure of its effectiveness. In sea sickness produced by motion of a visual field, the intensity of illumination is relatively unimportant. The information content of the stimulus rather than its energy is significant for the production of symptoms.

SENSORY MODALITY INTERACTION

Motion sickness may be produced by stimulation of the otolith organs, or by stimulation of the semicircular canals or by stimulation of the eyes. The movement of swings has been analyzed into linear and angular components. Neither component alone can produce as much motion sickness as the combination. Head movement that subjects the inner ear to more complex stimulation has been shown to increase the probability of motion sickness. Johnson and Mayne (ref. 42) achieved 60 percent reduction in incidence by fixing the heads of subjects in relation to the frame of the airplane in which they were riding. Manning's subjects (ref. 26) experiencing the same vertical acceleration as those of Wendt failed to develop motion sickness. The difference was interpreted by Walter Johnston (ref. 43) as being due to head fixation in one case and lack of fixation in the other.

The effects of visual stimuli when added to those of body acceleration are complex. Motion sensed only visually is quite adequate to produce motion sickness. The visceral sensation produced by a Cinerama rollercoaster ride must be experienced to be appreciated (ref. 63). Crampton and Young (ref. 12) demonstrated a significant correlation between the susceptibility of subjects to sickness produced by rotating a cylindrical visual environment about them and their susceptibility to sickness produced by acceleration.

Manning and Stewart (ref. 47) investigated the interaction of vision and acceleration in a swing. Three conditions were tested: one, the subject had full vision of the room in which he swung; two, he had no vision; and three, vision was limited to a small compartment which moved with the subject. With each successive change in condition the incidence of motion sickness increased. Thus, visual stimulation decreased or increased motion sickness depending on whether it aided or confused the subject's orientation.

When pilots fly as passengers they become more susceptible to air sickness. This change as well as the high incidence of air sickness among navigators and radio operators has been attributed to their decreased opportunities of visual orientation compared with that of a pilot in the cockpit. A well known method of reducing motion sickness is that of observing the horizon rather than parts of the vessel which partake of the same movement as the subject. Vision may increase or decrease the probability of development of motion sickness. Thus, stimulation of several sense organs simultaneously can lead to an increased production of motion sickness, but depending on the nature of the stimuli may reduce sickness.

Observations have shown that unusual stimulation of several sense organs is more likely to produce motion sickness than stimulation of only one. However, an increase in quantity or power of stimulation does not inevitably lead to an increase in number or degree of symptoms.

SENSORY MODALITY CONFLICTS

The experiments of Manning and Stewart (ref. 47) and those of Witkin (ref. 62) demonstrate clearly what is meant by sensory modality conflict and its significance in the production of motion sickness. The subjects of Manning and Stewart were swung under three different circumstances: no visual reference frame, a visual reference frame that was stable in relation to the subject's inertial reference frame, and a visual reference frame that moved with the subject. The incidence of sickness was greatest when the visual reference frame did not coincide with the inertial frame. It was least when the visual and inertial reference frame were the same, and intermediate in the case of excluded vision. In Witkin's experiments both the subject and the room surrounding him could be rotated independently about an anterior-posterior axis. With body movement alone, visual and inertial references in agreement, he observed no illness. He also observed no illness due to body movement when vision was excluded. Body movement with room movement caused occasional mild discomfort. Room movement alone caused the most severe discomfort and several subjects requested, after a few seconds, that the experiment be stopped. The greatest discomfort occurred at the points of reversal of the room's movement, that is, at the positions of greatest angular acceleration. Since the immobile subject's semicircular canals and otolith apparatus were indicating no angular movement they were in greatest disagreement with the visual information at those times when the room was reversing its movement. One unusually susceptible subject developed symptoms in a completely static situation. Neither she nor the room was moving, but the room had been tipped from the vertical. The amount of visual stimulation is certainly not unusual. However, the direction of vertical implied by visual stimuli and the direction of vertical implied by inertial stimuli are in conflict, and further, the discomfort of the subject is greatest at these times when the conflict is greatest. Symptoms are more likely to occur when accelerations sensed by the labyrinth are not corroborated by visual evidence or worse still are contradicted by visual stimuli. Such considerations led F. J. Kirkner (ref. 44) and others to speak of the cumulative effect of conflicting sensory impression.

These observations seem to indicate that sensory conflict in the absence of any strong stimulation is adequate to produce motion sickness. However, it does not prove that such sensory conflict is necessary for the production of motion sickness. Subjects in an open swing with full view of the room in which they are swinging experience no sensory conflicts, yet they become sick. Subjects riding a vertical accelerator with full view of their surroundings are subjected to no sensory conflict, but they also become sick. Sensory conflict can lead to motion sickness, but it is no more an essential than is strong stimulation of a particular sense organ. Also, in some subjects incongruent reference frames lead not to conflict, but to complete acceptance of one reference frame with the occurrence of illusions being the only consequence of having chosen the wrong one.

PSYCHOBIOLOGICAL DISORIENTATION

Orientation and disorientation have three main aspects. First is accuracy, the degree to which a mental or neurological image or representation of position, movement, and acceleration correspond to the real situation. Second is certainty, the degree to which the subject accepts, consciously and unconsciously, his existing orientation as the correct one. Third is consciousness, the degree to which the subject is aware of the first two factors, orientation and its certainty.

Whether or not a subject's orientation is accurate has little direct effect on the development of motion sickness. Disorientation of this sort may produce phenomena which the subject considers interesting or amusing, but as long as he feels certain of his own orientation he attributes these phenomena to some "peculiar" property of the environment. Spatial orientation or the reference frame against which the orientation of the subject and objects he observed is judged is not ordinarily a very conscious percept. The vestibular apparatus and the proprioceptive kinesthetic system make their contributions to ocular reflexes and motor behavior in general in a very quiet and unobtrusive manner. Most experimental subjects asked to indicate the direction of vertical do so without much conscious awareness of the sensory clues they are using. Features of orientation or the subjective reference frame are more likely to become conscious in novel situations or when the correct compensations are not being made smoothly. Conscious awareness of a decreasing certainty of orientation is called vertigo. This is not disorientation in the sense of loss of accuracy, but rather of decreasing certainty or faith in that accuracy. Naturally, the subjective judgement that the orientation is poor is usually a correct assessment of the facts.

The perception of one's orientation and the evaluation of its probable accuracy are largely unconscious processes. They are relatively resistant to correction through intellectual knowledge of the true situation. Witkin (ref. 62) said, "As in many other perceptual illusions knowledge about the true situation does not eliminate the induced perception of body movement. In some cases, after illusory body movement had been experienced, the subject was asked to look out the back of the room into the laboratory to establish that only the room was moving, but when he faced the front again the illusion of body movement typically returned. The intellectual awareness that the room and not he was moving did not diminish the impression that the converse was happening." Some subjects who were highly visually oriented were allowed to hold a plumb bob while the room was tipped. "With the room tilted, however, regardless of the position of the body, there occurred the most compelling illusion that the plumb was extended at an angle in the direction opposite to the tilt of the room and to an extent corresponding to the room's displacement." Only rarely did the subjects even consider the possibility that the free hanging plumb line was vertical. These subjects felt secure in their acceptance of an inaccurate orientation. Even though a sensory conflict existed, in determining their overall spatial perception so little weight was afforded to proprioceptive and vestibular sensations that they were disregarded.

Of these severely disoriented subjects, Witkin said, "Paradoxically some of the subjects who were very strongly influenced by visual impressions were not disturbed by visual movement precisely because they accepted the field to a very great extent. To such subjects the moving field appeared stationary throughout and only the body seemed to be moving. So strong was this impression that the subjects felt entirely certain of this orientation." Such subjects, though experiencing sensory conflict and highly disoriented, do not become motion sick. They show no indication of any internal recognition, conscious or unconscious, of their inadequate orientation. In fact, though incorrect, their orientation is adequate for all physical needs. They are in no physical danger in the experiment situation as a consequence of their illusions. In contrast with them stand some subjects of Crampton and Young (ref. 12) who experienced illusions of rotation due to a rotating visual field. "It is suggested that subjects who perceived apparent rotation tended to be unaffected. Those who perceived actual motion tended to experience nausea."

An illusion securely held does not produce symptoms. A more accurate perception arrived at with difficulty and held with uncertainty may do so. Witkin said, "the discomfort that occurred under these rather static conditions seemed to have been related to the difficulty she encountered in getting her bearings." Although she had accepted the room in a very tilted position," he said, "she had made her judgments quickly and usually stated that she though she was doing rather well. Thus, throughout this subject's performance a relation was apparent between illness and difficulty in determining position." Her illness was associated with uncertainty rather than the inaccuracy. These various items of evidence indicate that visual movement produces illness by providing an unstable situation in which it is difficult to remain oriented." It should be noted here that the actual correlation was not between illness and difficulty in remaining oriented (many symptom-free subjects found correct orientation impossible), but rather between illness and the difficulty in achieving an orientation acceptable to the subject. Witkin thought the subjects that became sick in the static situation of a tilted room or under the condition of a rocking room had a larger component of anxiety than is common in the usual motion sickness produced in body movement situation. This is probably related to the fact that the subjects were consciously aware of their inadequate orientation. Normal anxiety is a manifestation of consciously recognized threats. Any significant amount of anxiety in the absence of conscious knowledge of threat is pathological.

To this point the discussion has been devoted to reviewing the relative lack of dependence of motion sickness on the intensity of the primary sensory stimulus to any specific end-organ, to the lack of direct dependence of motion sickness on specific patterns of sensory stimuli and to pointing out that sensory conflict or even disorientation are not sufficient in themselves to cause motion sickness. The important missing factor is the manner in which a subject reacts to the above factors. Strength and pattern of stimulus are of little consequence to a subject who has successfully adapted to them. Disorientation is of little moment to a subject who feels no need for orientation, while asleep for example. In some circumstances a man can accept an erroneous orientation and live with his illusions. The man who becomes sick is the one who cannot accept his existing perceptions, be they right or wrong, but persists in the effort to improve them. Support of this view requires a discussion of the nature of perception.

PERCEPTION AS A BASIS FOR MOTION SICKNESS

Introduction

Stimulation of sense organs, the input to the nervous system, is merely the first step in a series of related and complex events which constitute the utilization of the information contained in the stimuli. The first stage of this processing, which creates in the organism a set of data corresponding more closely to the stimulus producing environment than to the interposed stimuli themselves, is called perception. The information, itself, after having been so processed may or may not be conscious. The majority of all information entering the nervous system is used, if at all without ever becoming conscious. However, if it is to be used effectively it must correspond to the environment it represents. Establishing and maintaining this correspondence is a serious and important neural function. Its failure leads on the conscious level to illusions, on the behavioral level to incoordinated and ineffective responses, and even at the visceral and vegetative level to less adequate and appropriate regulation of blood pressure and vascular tone.

The outstanding, and one might say defining, characteristic of normal percepts is their correspondence to reality.

Though there is great variability in the activity of primary sensory neurones there are invariant relationships in their patterns of activity which correspond to environmental invariants. These invariances or constancies are of the type which permit a static mathematical equation to represent a dynamic physical situation. For example, $X = 2Y$. X and Y may vary over a considerable range, but the equation states that they have a constant ratio of magnitudes, one being always twice as great as the other. A given object tends to have a fixed apparent brightness through a wide range of intensities of illumination. The perceived constant brightness corresponds to the constant ratio between incident and reflected light rather than to the actually varying quantity of light which leaves the object, enters the eye, and stimulates the retina. The perception of such a constant brightness corresponding to a constant ratio of reflected light is possible only if there are other clues available indicating the relative intensity of illumination. Brightness constancy is possible only against a background. Color constancy is maintained in the same manner. The perceived color of an object being a function of the relationship between the color composition of the incident and the reflected light rather than a function purely of the reflected light. Again, this constancy depends on there being available clues as to the true composition of the illuminating light.

In man, at least, these perceptual constancies are not completely inherent. The effect of learning or experience is evident in many of them. Novel experiences often give rise to illusory perceptions that disappear with increasing familiarity with the situation. For example, most people on their first airplane ride are intrigued by the apparent smallness of objects on the ground. As increasing time in the air provides increasing experience with the judgment of vertical distance, ground objects regain their normal size and are perceived as being at a more correct distance from the observer and of the proper size. Some critics of size constancy have held that an object must necessarily be perceived as smaller before disappearing from sight in the distance. Careful experiments under favorable conditions for seeing distance (ref. 25) have shown that objects maintain their apparent size as long as they can be seen at all, their size becoming only less determinate as indicated by increasing variability of size judgments with increasing distance. There are great individual differences in the manner of perceiving. The degree to which this is inherent or a function of past experience has not been clearly determined. However, some people, apparently with a less well developed sense of distance, do perceive distant objects as being smaller.

Information from several modalities can enter into some perceptions such as that of the vertical. This multimodal origin of some percepts allows for the possibility of modality conflicts. There are subjects who persist in utilizing one modality almost exclusively. Such subjects tend to suppress contradictory sensations arriving through other modalities. Consequently, observations of natural phenomena that would appear normal against the background of the suppressed modality appear paradoxical against the background of the accepted modality.

In understanding the functioning of the brain, the fact that the product of the process of perception, the percept, is often conscious is not its most important feature. Most research on the subject has dealt with the psychophysics of perception, that is, the relationship between the conscious reportable percept and the physical state of the observed environment. These studies have led to the very valuable concept of perceptual constancy and an appreciation of the great quantity and variability of primary sensory neurone activity which is sorted and collated to produce the stable percept. Through the study of illusions and the conditions necessary to produce and dispel them, much has been learned concerning the rules governing the quantitative and logical transformations performed on this data by the perceptual process. Ames (ref. 3) has made some outstanding studies of this type. Conscious awareness of the percept is a very private concern of the individual observer and varies considerably from one subject to another. An experimenter observing the behavior of a subject may be able to infer the presence of percepts, which the subject himself is not able to report. The same evidence exists for unconscious percepts as exists for any other forms of unconscious mental activity. They may be confirmed by leading the subject to conscious awareness of a percept that previously was implicit in his behavior, though unconscious.

From this point of view, perception is an unconscious data processing operation that converts primary sensory data into a neurological representation of the object or event that produced the stimuli. It tends to decrease the quantity and variability of the data while increasing the reliability of the information. It maintains a relative constancy between some environmental features and their ultimate neural representation. This constancy is gained at the expense of ignoring some sensory data or neutralizing variations in it. For example, color constancy of objects is gained at the cost of lack of awareness of the true color composition of the illumination.

Information entering the nervous system can be of value to the organism only when it contributes to the output of the nervous system, either immediately or at some later time through having altered the structure of the nervous system, and hence its response characteristics. Some information passes rather quickly from input to output, as in a single- or two-neurone reflex. Other incoming information influences the behavior or later state of many intervening neurones before it has any effect on a motor or output neurone. Such a condition of potential information paths permits an ordering in the organization of the nervous system with input and output elements considered as being the lowest level in this organization. Any intervening neurones are considered to be at a slightly higher level in the organization. An exactly analogous situation exists on the motor side of the organization. A given motor act corresponding to a conscious intent to move may require different patterns of activity in the motor neurones at different times or under different circumstances depending on such things as the physiological state of the muscles or the field forces or other types of impedance encountered by the moving members. The neural signals corresponding to a conscious intent to move pass successively downward until they culminate in a pattern of motor neurone activity and muscle contraction and relaxation.

Needless to say, the majority of information present in sensory neurone signals that contribute to the output of motor neurones does not pass through this entire circuit. Simple consideration of the information capacity of the various levels immediately precludes such a possibility. The most generous estimates of the capacity of conscious channels under ideal conditions place the capacity at less than 50 bits per second, and this only for short periods of time. A dozen of any ordinary sensory or motor neurone fibers have a greater capacity than this. Sensory input of muscle spindles and tendon organs contributes to the state of muscle contraction without necessarily becoming conscious. Pupillary and stapedius reflexes regulate the physical intensity of incoming stimuli. The perceived position and motion of a visually observed object are functions of the motor signals going to the extraocular muscles, as well as rational stimuli and the state of activity of the semicircular canals. Paralysis of an extraocular muscle or mechanical blocking of the eye movement, which ordinarily accompanies the nerve signal to that muscle, introduce distortions into perceived position and movement. An effort to move the eye, when not followed by that movement, is followed by an apparent movement of the visual environment in the same direction, at least until the paralysis has existed long enough to permit perceptual compensation to occur. Experiments have shown that subjects can be so conditioned that the perceived color of a constant stimulus object becomes a function of the direction of gaze.

Higher and higher levels of the nervous system are increasingly isolated from direct contact with the real world. This isolation serves two purposes and has many consequences. The intervening levels of perceptual data processing and motor programming free the higher levels from the confusion caused by accidental variables in a stimulus situation and permit the smaller quantities of data that are passed on for consideration at the higher levels to have a closer correlation with those features of the environment that are of significance to the organism. The value of such low level processing of such a large quantity of information can better be appreciated by observing a victim of cerebellar ataxia. Such a person has no loss of movement or weakness, but he is forced to exercise a higher degree of conscious control over his movements to substitute for the decreasing function of the cerebellum. Such consciously controlled movements are generally awkward and clumsy. A movement, which in a normal person would be a beautifully simple compound curve, must be broken into awkward segments more readily conceptualized and consciously controlled by the neurological cripple.

Inherent motor reflexes are joined by increasingly complex numbers of learned and often automatic movements, which are mainly unconscious. Conscious intervention or contribution to the activity of lower levels often consists of altering the loop-transfer characteristics of some of the sensory motor loops that have been organized at a lower level. This is a different type of control than merely adding a certain quantity of additional stimulation.

Sensory data may undergo perceptual analysis to the point where the information represents a fairly stable or percept type set of data. This information may then be applied to guide motor behavior, still at a relatively low level in the organization. The higher levels actually observe these lower ongoing activities rather than observing the external world directly. For example, the judgment of weight performed when an object is lifted by the hand is influenced by such things as postural reflexes originating in the labyrinth, the current sensitivity of the myotatic reflex, as well as by direct sensory report.

The advantages of perceptualization are simplification of the behavioral world and the consequent freeing of higher levels for other work. The disadvantage is the automaticity and the convincingness of the percept. We act as if the world were the perceived world.

Perception compensates not only for the variability of some of the accidental properties of the environment but also for the fallibility and shortcomings of the sense organs. Data from several sensory sources are combined, each contributing according to some weighting of reliability or significance or believability. The weight given to data from different sense organs varies from individual to individual. It is a function of past experience and of many features of any given stimulus situation. The best internal measure of perceptual success is consistency. Consistency means containing minimum novelty, the least deviation from previous experience. Consistency of sensory input at a given moment is the same as its redundancy. The greater the consistency the less the information content.

Perception of Space

Perception of space is achieved by integrating the contributions from many separate sense organs. Much of this data is applied at a very low level to directly influence motor behavior. Tendon reflexes are a good example. Righting and postural reflexes are others. Behavior of such complete loops serve as items of input to be integrated again on a higher level. Some of the information may eventually be passed as high as a conscious percept. On the motor side an intent to move does not go directly to muscle, the neural signals actually arriving at a muscle as a consequence of an intention to move are greatly altered by the state of sensory receptors, the activity of which is far removed from consciousness. What does reach the conscious level is integrated and abstracted from the activities of the many lower organizational levels.

Visual field is generally an inertially stable one. It does not undergo acceleration, angular or linear. Normally, a subject's inertial reference frame (IRF) coincides with this field. When the subject undergoes angular movement relative to this inertial reference frame, it is of obvious advantage to have the eyes stabilized with reference to it and hence to the visual field rather than with reference to the subject's moving body. The movements of the eye relative to the body that are required to keep the eyes fixed in relation to the IRF are called nystagmus when quick movements in the opposite direction become necessary to keep the eyes within their normal range of movement.

The inertial reference frame in turn is determined by two major sensory inputs: the non-auditory labyrinth (semicircular canals and maculae) and the visual field itself. Ordinarily these two referents are in agreement. When they are not, the inertial reference frame is less well determined and which factor predominates depends on the relative strength of vestibular stimulation, the structure of the visual field and the training or experience of the subject.

The simple description above applies only to the rotation about the vertical axis. For rotation at an angle to the vertical, in the best studied cases about an axis at right angles to the vertical, there are other sensory inputs to consider, the otolith organs and the tactile proprioceptive-kinesthetic system (TPK). These two inputs have features more in common with the visual field than with the semicircular canals, that is, they persist in time. Semicircular canal input is in response to angular acceleration and in a state of steady rotation tends to report either no rotation or very slow and uncertain rotation, drifting. Otoliths and TPK report direction and intensity of linear acceleration and can continue to do so for an indefinite length of time without drifting.

Because of these modality differences, the inertial reference frame has different inertial properties for rotation about vertical axis and for rotation through any other axis. Though some highly visually-oriented subjects will report themselves as inverted when they have observed their visual environment being inverted, and all stories of pilots who flew inverted for some time without being aware of the condition are not apocryphal, the clues available to either type subject, were he to attempt physical movement, are more than adequate to correct the illusions.

The perceived vertical or the vertical of the IRF is not always the same as the direction of linear acceleration of a subject's head. If it were, the earth would appear to tip whenever we drove a car around a corner. For such short periods the semicircular canals dominate sufficiently to prevent rotation of the IRF and the situation is perceived naturally. For a longer duration of such a motion, as on a centrifuge or amusement device, the situation is somewhat different. The semicircular canals are effective in preventing rotation of the IRF vertical for less than a minute. For rotations continuing longer than this, only visual influences are available to maintain IRF vertical parallel to gravitational vertical. If these are removed, as in the dark, or tend to reinforce the otolith and TPK vertical, as in a closed and swinging centrifuge cab, clues to geographical vertical are very weak, leaving nearly everyone no choice but to accept the acceleration vertical for his IRF. Even with full view of a stable environment, the otolith TPK input may predominate. A logical, natural relationship exists between perception of moving in a circle and perception of vertical. By implication, if the otolith vertical coincides with the geographical vertical, the subject is not moving along a curved path. Hence, the acceptance of this otolith picture for the IRF vertical implies simultaneous acceptance of the absence of such movement. The subject then perceives himself as stationary and his environments as being tilted and rotating about the axis about which the subject himself is actually rotating, but of course in the opposite direction. With some subjects, the alternate perception may be controlled by choice. Needless to say, these logical relationships are not necessarily preserved in all subjects any more than are all the other logical relationships which are inherent in the real world. Subject variation does occur.

Graybiel (refs. 28, 29, 30, 31, 32, 33) for many years has been responsible for an excellent series of experiments that bear out these relationships, though in general he has not discussed them in terms of the subject's IRF. He has usually induced a change in the subject's IRF through one modality, suppressing sensory clues as required to allow this, and then measured the shift in IRF through another modality. He refers to this measured shift by such terms as oculogyral, oculogravic, or audiogravic illusions, depending on the modalities employed for input and output. On occasion, he has referred to the subject's "ego-centric vertical" and its determination by one or another modality. This is the same as the vertical of the subject's IRF.

Some of his earlier work on oculogyral illusions, in which he did not refer to the subject's IRF, but attributed the results specifically to the nystagmus— an observable manifestation of the subject's rotating IRF has been criticised for this omission. Van Dischoeck, Spoor, and Nuhoff (ref. 18) performed experiments in which nystagmus was divorced from the subject's IRF by virtue of extraocular muscle paralysis and others, in which retinal tracking was reversed to a slight degree by lenses. They found that the reported movement of observed point light sources coincided with that expected from the behavior of the subject's IRF as inferred from his reports of sensation of body movement. They concluded that the optogyral illusion is a central process caused by vestibular stimulation which is not causally related to the nystagmus of the eyes. Jongkees (ref. 18) has repeated Van Dischoeck's experiments and come to the same conclusions.

Perceptual space and the IRF possess properties other than the purely directional. The physical forces that determine the vertical have intensity as well as direction. This intensity has an influence on any movement made by a subject. The accomplishment of any consciously, or unconsciously, initiated movement requires components of muscle effort to prevent the movement that would be passively produced in the limb by these acceleration forces. This component is normally itself an unconscious one. When the accustomed 1-g vertical force is experimentally increased or decreased, the errors in quick, consciously directed movement show the effects of the normally unconscious 1-g corrections. If the task is that of striking a target, the 1-g compensation proves too great in a decreased field and too slight in an increased one and the hits are accordingly too high or too low (figure 1). Experiments which excluded vision are striking as the effect of visual monitoring and conscious corrections are eliminated. Even with vision permitted, the effects are evident in the increased dispersion of the score, visual guidance with conscious correction being less accurate when they must correct for the unfamiliar g forces as well as for the normal errors of movement. With prolonged exposure to an altered g field the corrections tend to become more appropriate and automatic. A simple demonstration of this may be made easily. The bouyancy afforded by water immersion neutralizes most of the effects of the normal 1-g field. On emerging from a swimming pool after an appropriate time, anyone may experience body and limb heaviness. The first few steps and other movements may show considerable clumsiness. This is not simple weakness or fatigue, because the heaviness and clumsiness vanish in a few moments as soon as the unconscious 1-g compensation is reactivated.

The otolithic component of this experience is revealed by a "heaviness" that is experienced rather than a weakness of movement in any direction. However, though labyrinth factors can determine the direction in which an unconscious contribution is added to the efforts of moving, they cannot be the only source for such compensatory muscle action. An enlightening illusion is easily produced. If the arm is held rigid at the elbow and a serious attempt made to abduct it at the shoulder for about 1 minute with the movement of the arm being prevented by standing with it close against the wall or other immovable object, a feeling of levitation will be experienced when the effort is halted and the arm allowed to hang freely. It may rest as much as 15 degrees from the vertical or even continue to rise. Returning it to the same relative position as the unexercised arm occupies at rest requires a conscious effort. The experience is similar to pushing against a soft intangible spring, or more correctly, it corresponds to effort required to move a freely hanging arm slightly from its normal vertical position.

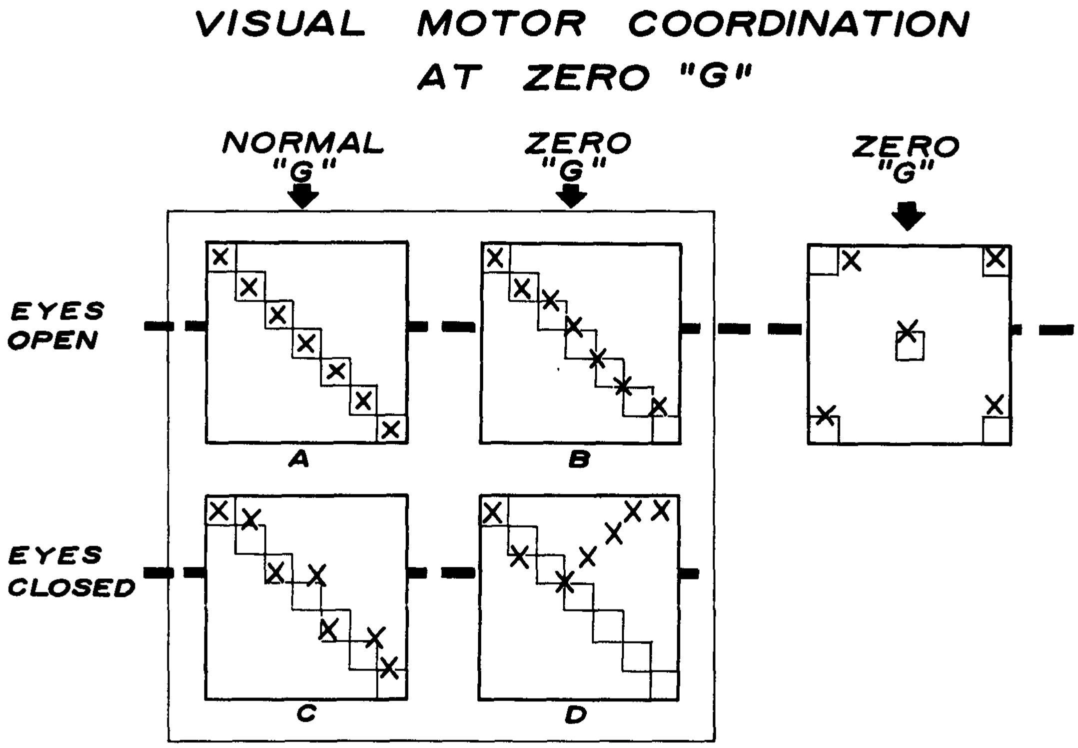

Figure 1. Visual Motor Coordination at Zero g

Typical performance of von Beckh's subjects who were required to strike a target at arm's length. The reduced ''g'' was obtained by parabolic flight.

Such unconscious corrections occur not only for the vertical component of movement, but for others as well. When the mass of a moving member is altered, as by wearing heavy shoes, a greater effort is required in starting and stopping movement in any direction. At first, wearing unusually heavy shoes, or on first reverting to lighter ones, there is a period of adjustment during which actual movements do not coincide completely with intended movements. However, the corrections required are soon incorporated in the unconscious portion of the control system, and once again the constant relationship exists between intention and movement.

Indeed, this facility for compensation for changing mass and other impedance characteristic of our limbs goes so far that we are ordinarily slightly, if at all, aware of the real physical characteristics of the members of our own bodies. Perceptually we perform in a near zero-g field at all times. This predominance of the properties of the neural control system over the actual physical properties of the controlled member has been demonstrated in several experiments. Warren G. McCulloch*, in about 1944, attempted to alter the frequency of tremors by mechanically loading the oscillating members. The effect of changing the mass of the physical part of the system showed that the frequency was almost totally determined by the transfer characteristics of the nervous control system.

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The ability of the nervous system to compensate for changing mass of the limbs and for changing intensities or gravitational field actually goes much farther than the simple cases illustrated. It is capable of introducing compensation for even more dynamic situations. This is the basis for accommodation to the movements of a ship. To the sailor who has not yet achieved the correct compensation, the horizon tips back and forth and mysterious forces deflect his feet, making simple walking quite difficult. When the proper compensations have occurred the IRF is stable, as indicated by the stability of the horizon. The compensation may become so thorough that it persists after the movement for which it compensates has ceased. Thus, the well adapted sailor may find the land pitching and tossing. This no longer correct compensation may last for hours and has been called "land sickness" (refs. 9, 52).

Perceptual Adequacy

Whether a perceptual process carries the transformed and integrated data all the way to a conscious percept or whether the organization is completed and used in regulation of motor output at a lower level, if the percept is not an accurate representation of the real world, that inaccuracy will be reflected in the conscious percept or in any behavior to which the unconscious percept contributes.

The pragmatic test of perceptual adequacy is that the percept's contribution to behavior enhances the effectiveness of that behavior. Ineffective behavior is the strongest stimulus to the reorganization of perception on a new basis. Since perception of a dynamic situation must also involve prediction of future stimuli, comparison of predicted stimuli with experienced stimuli, both conscious and unconscious, provides another check on the success of perception. And finally, perception is based on a redundant field of data. Unless this redundancy can be reduced to a single, self-consistent percept, something is amiss in the perceptual process. A judgment of consistency must always be made against a background of experience. Reality is always consistent and any set of conflicting percepts must be the consequence of inadequate perception. Unfortunately, this is not an absolute test. Current data conflict may indicate that the present experience transcends all previous experience and that the reference system in which the conflict is possible must be replaced by another more general system in which the current data is no longer in conflict. Subjects differ in the manner in which they make these readjustments.

When first encountering a well structured visual environment in which the implied vertical differs from the acceleration vertical, some subjects recognize that the room is tilted (obviously the most satisfactory perception). Others compromise and perceive a vertical IRF in some position between the visual and the acceleration vertical. Others accept the visual vertical even to the extent of suppressing physical sensation and reporting, on direct questioning, physical sensations that corroborate, or at least do not deny, the visually implied vertical. This suppression is an important feature of the perceptual process and normally serves to eliminate the ever present errors due to sensory fallibility. Such subjects are willing to offer rationalizations, which from their orientation break some of the fundamental laws of physics, rather than accept an IRF in which the room would appear tilted. It would be very interesting to observe the behavior and possible perceptual reorganization of subjects were they allowed to move about freely in such a tilted room. It is known that engaging in physical activity aids in the formation of the proper percepts in sea voyagers and hastens their adaptation to ship movement.

There are many activities not worth the effort. The subjects who naively accept completely erroneous IRF come off better than those who puzzle excessively to produce a better one even though they may meet with some success in their efforts. The accepting subjects experience no vertigo, anxiety or nausea. Of course, they are poorly equipped to engage in any physical activity while so erroneously oriented, but in the experiments described none was required of them.

Successfully achieving a new IRF, involving the dynamic properties if necessary to compensate for a ship's movement, provides the subject with a more general reference frame, in which data no longer conflict and intentions to move result in the intended movement and not in some mysteriously deflected one.

Perceptual Theory of Motion Sickness

Perception is a processing of sensory data that trades on the redundancy of the data to provide a more probable representation of the real world than is afforded directly to the sense organs. This consolidation of data and its application to behavior takes place at many levels in the nervous system from single synapse reflexes on up to conscious percept. The higher levels experience only what is passed to them from the lower levels. This permits our world of conscious experience to be a manyfold simplification of the world of primary sensory neurones. It also permits it to be a more accurate representation of the important features of the real world, many of the accidental variables being canceled out in the process of perception. The quantity of data so handled is tremendous, The cerebellum, the largest single collection of neurones unconsciously influencing motor behavior, is nearly commensurate with the cerebral cortex. Reorganizing the behavior of so large a mass of cells capable of handling so large a quantity of data is no small job. It can lead to symptoms.

The perceptual processes, at least of higher mammals, are quite flexible. They may be conditioned to compensate for a wide variety of systematic distortions induced in the sensory field. Adjustment to wearing glasses is probably the most common example of such compensation. It is but the task of a moment for anyone who has or can borrow a lens to convince himself that not only does the lens alter the point of focus of light entering the eye, but that it also imposes a distortion on the visual field seen through it. All magnifying or reducing lenses displace points seen through them either away from or toward the center (figure 2). Most cause straight lines which do not pass

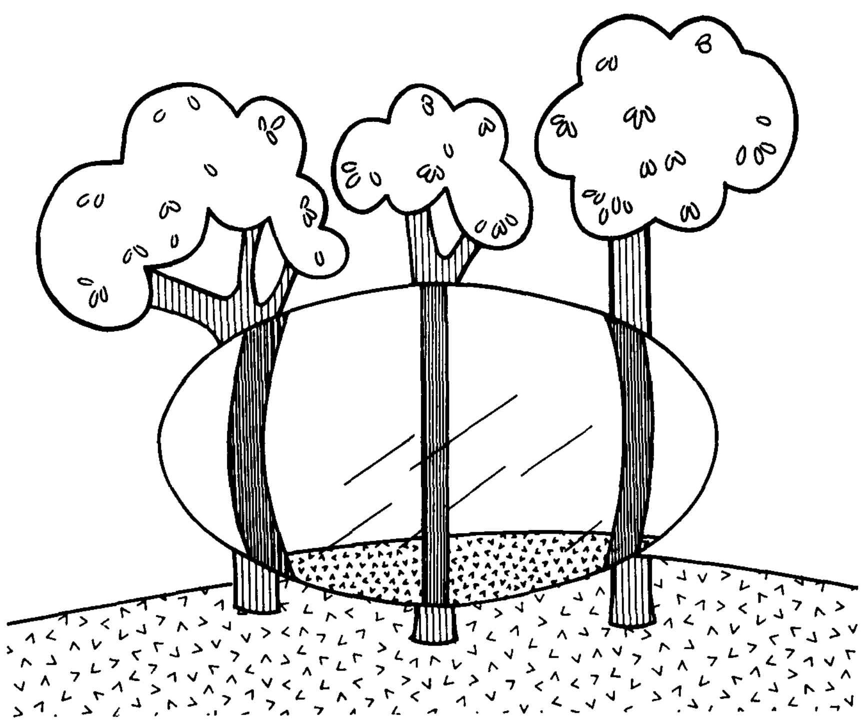

Figure 2. Distortion Produced by Reducing Lens

through their centers to appear curved. Any movement of the head together with a lens fixed to it causes a displacement of the visual field seen through the lens. To most people who wear glasses, these distortions are perceptually suppressed and the world appears normal. In fact, to one long accustomed to moderate strength lenses, the world partakes of movement, dependent on head movement, when the glasses are first removed. It is common knowledge that nausea and other unpleasant symptoms may accompany the first wearing of new glasses. This persists until new ways of perceiving are achieved which once again allow the visual perceptions to be in harmony with the inertial.

Kohler (ref. 45), in an experiment with extreme perceptual distortion, completely reversed the visual field, right for left. He experienced some motion sickness symptoms for the first few days. These symptoms were again evident on removing the lenses many days later after adaptation was far advanced. The symptoms were relieved by antimotion sickness drugs.

Motion sickness and the development of resistance to it show many of the same traits as these other situations in which perceptual readjustments are made. The adaptation shows characteristics of learning, such as the effects of practice, forgetting, specificity, and some transfer to similar situations. Adaptation is accompanied by correct perception of the physical situation. The horizon no longer rocks. Successful adaptation often shows perserverance for a short time after the situation for which the adaptation has occurred no longer exists. Solid land may be perceived as pitching and tossing following a voyage (refs. 51, 52). The ability to adapt to the motion of a ship is decreased in certain people who have had dietary deficiencies and in some who have had injury to their central nervous system as by trauma or encephalitis (refs. 14, 15). Inability to compensate for the erroneous impressions produced by a damaged or weakened labyrinth has been considered evidence of brain damage.

Unfortunately, how one perceives is not under conscious control. If it were, such efforts at perceptual organization would not be pursued to the point of producing the uncomfortable symptoms of motion sickness. However, a subject engaging in such activity is no more able to cease it than is a victim of anxiety due to the existence of conflicts on another level of mental activity, though both may be aided by the same drugs. The preservation of a correct orientation to gravitational and other forces is a vital function. Its failure has killed many men. Maintenance of adequate blood circulation also requires acceleration data. Therefore, it is not at all unreasonable that the nervous system should persist so diligently in attempts to achieve an adequate inertial reference frame.

Need for reorganization of spatial perceptions is the common characteristic of all victims of motion sickness. This need is relatively independent of the intensity of sensory stimulation. It may arise in extreme cases even in a static situation to such a degree as to cause symptoms. There are situations, of course, in which intensity may be the parameter showing significant novelty. The 3-1/2-g variation experienced in the usual experimental zero-g parabolic flight is a good example. However, as in other circumstances, adaptation or learning does occur. It occurs not by the development of insensitivity to the sensory stimulus, but by the development of appropriately graded reflex responses e.g. cardiovascular, etc.

The adapted (hence resistant) and the unadapted (still susceptible) subject may experience reasonably identical sensory stimulation when in the same physical environment. One becomes ill, one does not. The difference is in the manner in which they perceive their environment, that is, the manner in which they process the sensory data. To the adapted subject the stimulus information is consistent, it has a high redundancy and can be processed to a percept of relatively low information content. The unadapted is unable to achieve this consistent low information content percept.

It is difficult to analyze the situation further to determine the relative significance of the higher information load passed on to the rest of the system by the failure to achieve an acceptable perceptual reduction as compared to the neurophysiological task of attempting to achieve a satisfactory reduction. The latter activity has all the properties of learning. Both activities, however, represent increased neural activity.

This increased neural activity is fundamental to motion sickness. Such a state of heightened activity in the nervous system has been termed "vigilance." Many types of loads on the nervous system other than the maintenance of spatial orientation are capable of inducing somewhat similar symptoms. Prolonged exposure to intense sound has produced headache, nausea, and increased irritability and fatigue. The stress of anticipating an important examination may induce nausea in students.

Together these observations tend to indicate that the nausea and other autonomic symptoms are produced by an overload of the central nervous system rather than an excess of stimulus intensity to any sense organs. More correctly, since the symptoms often anticipate the arrival of the actual information, as in pre-examination nausea, the symptoms are due to the state of heightened vigilance created in the central nervous system by the need to handle excessive data or by the anticipation of such need. Motion sickness may thus be considered as one of the better known and more frequent manifestations of a larger and less specific "vigilance syndrome" whose physiological basis is that state which portions of the central nervous system achieve in handling or preparing to handle excessive loads.

In this view of motion sickness, motion provides a field of sensory data requiring perceptual integration. In a broad general syndrome this field of data may be provided in various ways, even as abstract ideas. The need for adequate perception of acceleration forces and motion in the accomplishment of even simple, effective motor activity provides the drive for the continued "efforts to achieve" a satisfactory perceptual collation of the data. Fear of falling is the conscious manfestation of this drive in the case of spatial perception. In a more general vigilance syndrome other anxieties become manifest.

Sensory conflict serves as the clue that existing perceptual organization is inadequate; vertigo is the conscious manifestation of the absence of an acceptable perception organization of spatial and inertial stimuli. It indicates unwillingness to attribute validity to an existing orientation. Simple erroneous orientation results only in illusions, an entirely different experience.

SUMMARY

This report discusses the inadequacies of theories of motion sickness which attach too much importance to the intensity of stimulation or to the particular modality stimulated. Motion sickness is the result of strenuous attempts to solve a difficult information processing problem. It results from the effort made to solve, not specifically from the failure to solve, which merely motivates further effort if the need persists. The problem is that of maintaining spatial orientation or orientation to and compensation for accelerative forces. This involves the maintenance of an inertial reference frame and the perception of movement relative to it. The problem is made difficult by novel environments which invalidate customary approaches to the integration and interpretation of sensory data and to the programming of muscular movements.

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